

SHEAR FORCE MAPPING: A TOOL FOR TENDERNESS MEASUREMENT¹

H. ZUCKERMAN

*Food Engineering and Biotechnology
Technion, Haifa 32000, Israel*

AND

B. W. BERRY, J.S. EASTRIDGE and M.B. SOLOMON²

*Food Technology and Safety Laboratory
USDA, ARS
Beltsville, MD 20705*

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ABSTRACT

A shear mapping method (SMM) was developed and evaluated for examining objectively the effectiveness of tenderization processes for meat. One-centimeter square cross section samples were cut parallel to the muscle fiber orientation across the complete cross sectional area of cooked strip loin steaks. Each sample was assigned a coordinate reference grid code that identified ("mapped") its location within the steak. Shear force measurements within steaks were evaluated using the SMM procedure before and after applying the hydrodynamic pressure (HDP) tenderization process. The less tender the region within a control steak, the more it was tenderized after applying HDP, and HDP tenderization resulted in improved uniformity of tenderness. The suggested SMM method has the potential to minimize variations in technique among scientists and institutions and provides a tool for screening and testing the efficiency of tenderization processes by evaluating a larger proportion.

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²Address inquiries to Dr. M.B. Solomon, USDA, ARS, FTSL, Bldg 201, BARC-East, Beltsville, MD 20705. TEL: (301) 504-8400; FAX: (301) 504-8438; E-mail: msolomon@anri.barc.usda.gov

INTRODUCTION

Tenderness is one of the most important sensory qualities of meat and ranks among the first quality criteria a consumer considers when making a purchase decision for a cut of meat. It is well documented that there often exists a large variation in the rate and extent of postmortem tenderization when meat is aged (Alsmeyer *et al.* 1965; Morgan *et al.* 1991a; Shackelford *et al.* 1997). Inconsistent tenderness both within and between steaks from a given meat cut is one of the biggest problems facing the beef industry (Morgan *et al.* 1991b). Most studies provide some indication of the degree of variability associated with instrumental measures of tenderness, but generally do not report or document tough and tender regions within cross-sections of steaks.

AMSA (1995) guidelines provide a recommended procedure for instrumental measurement of tenderness using core samples. At least six cores should be obtained from each treatment regardless of species being tested (more are acceptable as long as they are "good" cores). If a small portion is tougher than the rest of the steak, this difference may not be observed and probably would not be statistically significant because it might be 'diluted' or discarded as an 'outlier' value when averaging the cores across the steak surface. Dransfield and MacFie (1980) determined, that due to the variability within the longissimus muscle, ten shear determinations were necessary to assess tenderness of that muscle.

The challenge of identifying an objective method for tenderness assessment across the complete area/surface of a steak raised the concept of obtaining as many samples to examine as possible from within the steak in a rapid and easy manner. Mechanically, in using the coring technique it would be difficult to completely assess the tenderness gradient across an entire cross-section of a steak. Furthermore, adequate and precise information on the tenderness profile of meat before a tenderization treatment is applied is important in assessing the performance of the tenderization process.

Hydrodynamic pressure wave technology (HDP), which uses an underwater detonation of explosives to generate a hydrodynamic shock wave pressure front, has been shown to be an effective process to tenderize various muscles (Solomon *et al.* 1997; Solomon 1998; Eastridge *et al.* 2000). However, the effectiveness of the HDP process in reducing tenderness variability across meat cuts is not known. Therefore, the objectives of this study were to (1) develop and evaluate a standardized and informative objective technique for tenderness evaluation according to location within a steak [shear force mapping method (SMM)]; (2) use the SMM to determine the ability of a postharvest tenderization process, HDP, to reduce the inconsistency in tenderness of cuts of meat.

MATERIALS AND METHODS

SMM for Screening and Evaluating a Tenderization Process

This part of the study was performed using seven fresh boneless paired strip loins from the lower third of the U.S. Select grade. The fresh U.S. Select grade loins were removed from the carcasses 3 days postmortem, vacuum-packaged and stored at 4C. At 5 days, postslaughter the loins were equally divided into 10 cm thick sections parallel to the rib end and loin end cut surface. The sections were randomly assigned to either hydrodynamic pressure process (HDP) or control (C) nontreated samples. After applying HDP, both HDP and C meat sections were cut into 2.5 cm thick steaks and frozen. These steaks were thawed for 18 h at 4C, cooked (described below) and analyzed for tenderness using the SMM procedure.

HDP Treatment

Meat samples designated for HDP treatment were first vacuum-packaged in a polyolefin resin bag (Cryovac/Sealed Air Corporation, Duncan, S.C.). The packaged meat was then placed in a polymer of isoprene (rubber) bag. This outer isoprene bag was also evacuated. The packaged meat samples were placed in a cooler filled with ice until treating with the HDP process. The packaged meat was placed on top of a 2 cm thick steel plate located on the bottom of water-filled plastic containers (115 L volume; 51 cm diameter) situated below ground level as described by Solomon *et al.* (1997). A binary explosive (100 g mixture) was immersed into the plastic container to a distance of 38 cm above the steel plate (Solomon *et al.* 1997) and detonated. Control samples were vacuum packaged in polyolefin resin bags only and placed in the cooler with ice along with the samples for HDP treatment.

Cooking

Individual steaks were thawed at 4C for 18 h prior to cooking. Steaks were broiled in a Farberware convection/broiler oven (Model T-4850, Hanson Corp., Bronx, N.Y.) to an internal temperature of 71C. Steaks were turned mid-way between the initial temperature and 71C. Internal temperature was monitored using iron-constantan thermocouples inserted into the center of each steak and attached to a Speedomax multipoint recording potentiometer (Model 1650, Leeds and Northrup, North Wales, Pa.). After cooking, all steaks were allowed to cool to room temperature (~25C) before sampling for shear force.

Shear Mapping Method-(SMM)

Frozen/thawed boneless strip loin steaks from carcasses representing the lower

third of U.S. Select quality grade were used to demonstrate the SMM. The standard procedure (AMSA 1995) for shear force tenderness is often measured as the force needed to shear a cylindrical core (1.27 cm diameter) of meat. Chrystall and Devine (1991) suggested that samples with a square cross section area were better in ensuring repeatability than a cylindrical surface. The SMM used test sample strips with a 1 cm x 1 cm cross section in area and a 2 to 3 cm length, parallel to the fiber axis (Boccard *et al.* 1981; Honikel 1998). In the SMM procedure, samples were removed from the entire area of the cooked steaks (described below) rather than using a few representative samples from different locations within the steak. Each sample was assigned a coordinate reference grid code or index that identified ("mapped") its location within a steak. The matrix indices are depicted in Fig. 1. The epimysial connective tissue (CT) dividing the medial (M) from the lateral (L) portion of each steak served as an anatomical reference point (arrow in Fig. 1). Column designations ran parallel to the CT with column numbers increasing as sampling moved towards either end of the steak, either laterally or medially. Rows were perpendicular to columns and were numbered starting at the subcutaneous edge of the steak. Figure 2 reflects the steak trimmed of fat before

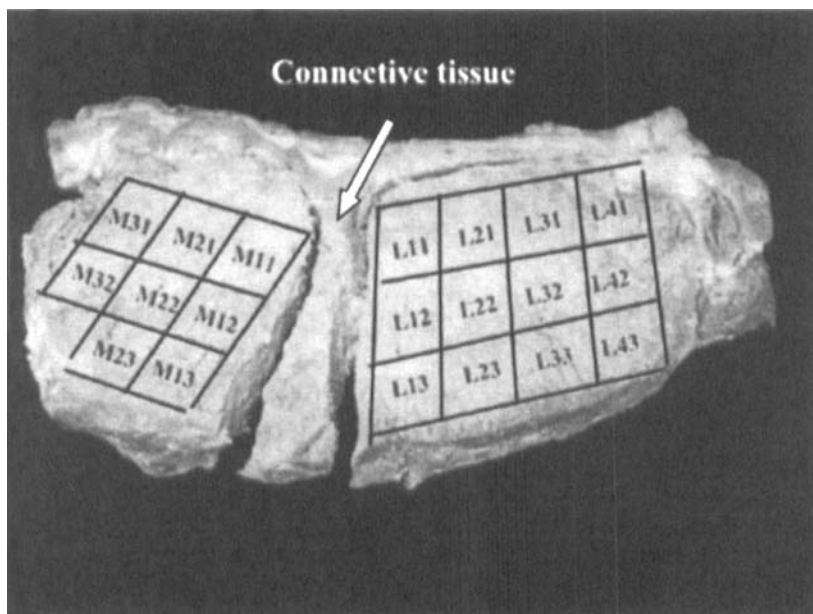


FIG. 1. "MAPPING" THE STEAK

Connective tissue dividing the medial (M) portion from the lateral (L) portion labeled. Column designations running parallel to the CT with column numbers increasing towards either end of the steak. Rows are perpendicular to the columns with numbers starting at the subcutaneous side of the steak

cutting the 1 cm² cross-section pieces. The arrow designates the CT reference point separating the medial (M) portion from the lateral (L). The number of rows/columns are not fixed, but vary according to the cross-sectional area of the steak. Each row and column extends out as far as possible in getting good samples. The technique of cutting and measuring using a caliper is also depicted in Fig. 2, that is, cutting columns followed by cutting these columns into 1 cm x 1 cm cross-section samples. Only minor trimming was necessary due to changes in the muscle fiber orientation. Each sample was sheared once at right angles to the fiber orientation using a Warner-Bratzler shear test cell mounted on a texture measurement system (Model TMS-90, Food Texture Corp., Chantilly, Va.) using a 3.18 mm thick blade, V-notch shaped, and crosshead speed of 25 cm/min.

Statistical Analysis

Statistical analysis was conducted using the PROC-MIXED procedures of the Statistical Analysis System (SAS 1996) program. The model for comparing shear force values included location within the cross-section of the steak (i.e., coordinate reference codes, medial region and lateral region). The random effect of animal, with the corresponding interaction was also included in the model.

RESULTS AND DISCUSSION

SMM Procedure

The SMM provided a minimum of 9 samples from the medial region and a minimum of 16 samples from the lateral region of each steak totaling a minimum of 25 shear force determinations. Minor amounts of trimming were required and generally was performed to correct for fiber orientation before the final rectangular sample was cut. There was no need to exclude samples due to defects in fiber orientation or sample defects for shear force assessment. Areas of marbling or blood vessels can easily be avoided when sampling and twisting of samples or hourglass shape problems from the coring technique was not a problem with the SMM procedure. Slight variation in the application of the coring technique between operators can lead to inconsistent diameter cores (Kastner and Henrickson 1969). Uniform sample size (thickness) can be verified through the use of a caliper (Fig. 2). With the 1-cm square strip section, it was easy to obtain uniform samples parallel to the muscle fiber orientation which is an important factor in ensuring repeatability (Boccard *et al.* 1981; Chrystall and Devine 1991). The time/labor involved for the SMM procedure does appear to be slightly longer compared to the standard coring procedures (Zuckerman and Eastridge personal communications; Eastridge and Solomon 1996). However, time/labor is diminished with experience and more shear samples are obtained with the SMM method. Furthermore, a shear

force tenderness profile across the complete area/boundary of a steak can be obtained (Fig. 1).

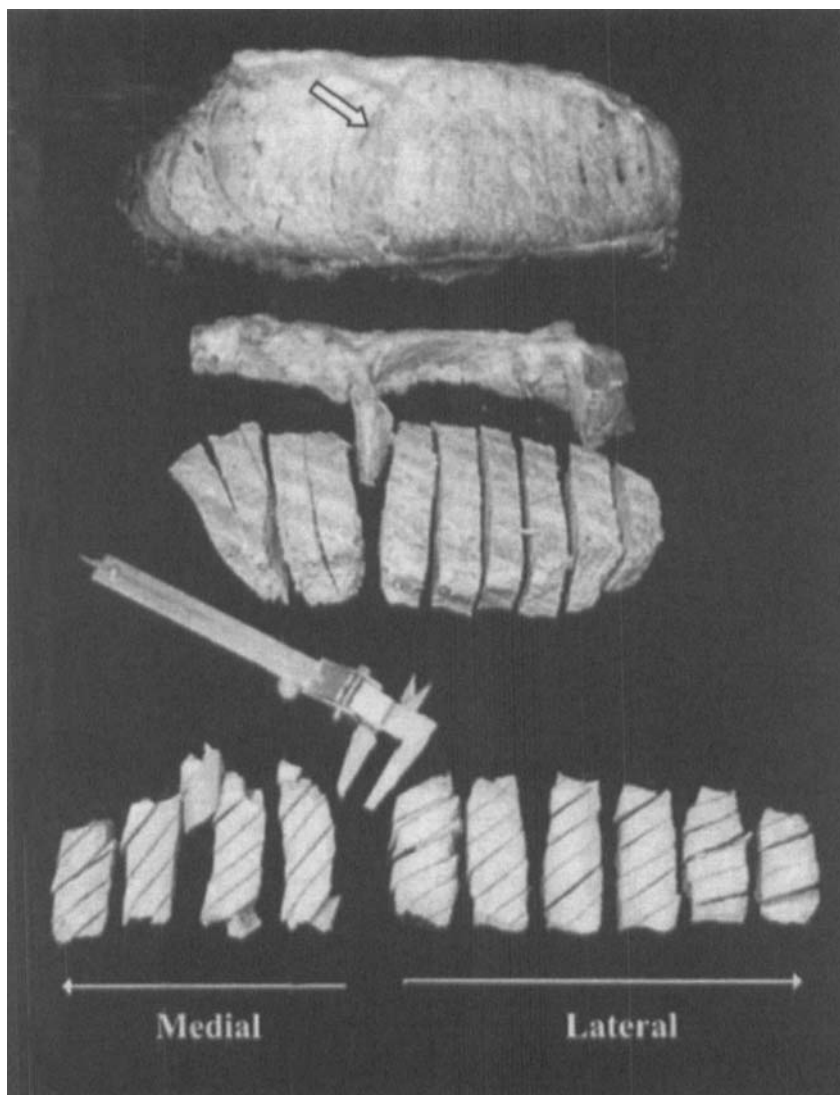


FIG. 2. SAMPLING A STEAK FOR SHEAR FORCE MAPPING

Connective tissue (CT), designated by the arrow, serves as an anatomical reference point for dividing the medial (M) portion from the lateral (L) portion of the steak (top picture). Trimming of the fat (middle picture) and cutting both the medial and the lateral portion of the steaks to 1 cm columns. Cutting columns to sample cubes (1cm × 1cm × 2-3cm length) parallel to the fiber orientation (bottom picture).

SMM Before and After HDP Treatment

The tenderness profile of the steaks from the seven low U.S. Select matched pairs strip loin sections before and after applying the HDP process is presented in Fig. 3 and 4 with medial, lateral and overall means shown in Table 1. The figures are three-dimensional representations of shear values averaged for each grid location using the SMM. The X-axis represents the column parallel to the CT and the Y-axis represents the rows perpendicular to columns. Each combination between the X and the Y represent a specific anatomical location index. The Z-axis is the average shear values obtained. Means and SD at the different locations for the control steaks are also presented in tabular form (Table 2) for clarity.

TABLE 1.
AVERAGE SHEAR VALUES FOR CONTROL AND HDP^a TREATED STRIP LOIN STEAKS

Region of steak	Shear Force, kg		
	C	HDP ^a	% I ^b
Overall	4.39±0.49	3.27±0.32**	25.50
Medial	4.13 ±0.66	2.94±0.25**	28.80
Lateral	4.57± 0.37	3.55±0.28**	22.30
SEM	0.73	0.39	-

**Difference is significant ($P < 0.01$)

^aHDP = hydrodynamic pressure process

^b% I = % improvement from C to HDP

TABLE 2.
MEAN SHEAR FORCE VALUES FROM CONTROL STRIP LOIN STEAKS (N=21) BY
ASSIGNED REFERENCE GRID INDEX

M33 3.91±0.1	M23 4.18±0.3	M13 4.29±0.2	L13 4.06±0.3	L23 4.88±0.7	L33 4.57±0.2	L43 5.17±0.1
M32 4.15± 0.8	M22 3.40±0.2	M12 6.30±0.7	L12 3.35±0.4	L22 4.78±0.5	L32 5.35±0.3	L42 4.11±0.2
M31 3.29±0.7	M21 3.57±0.4	M11 3.82±0.3	L11 4.92±0.1	L21 4.47±0.2	L31 4.74±0.3	L41 4.02±0.1

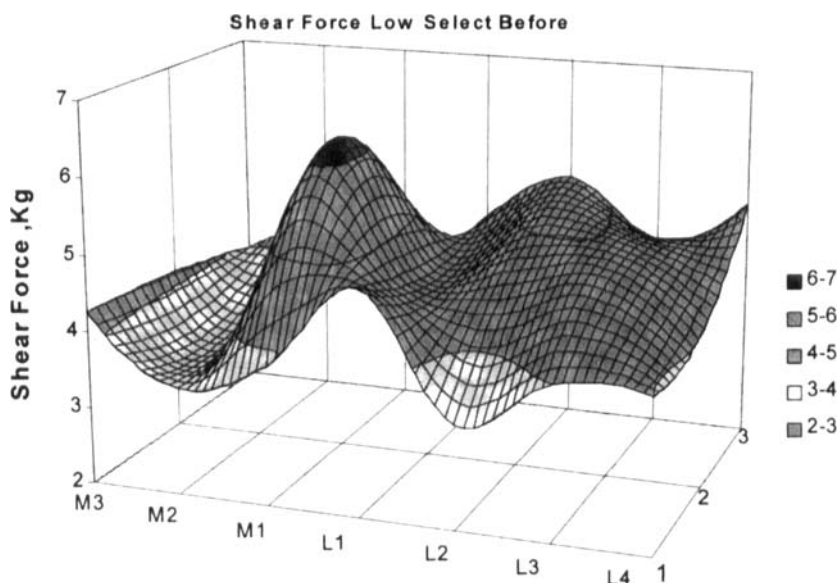


FIG. 3. THREE-DIMENSIONAL REPRESENTATIONS OF SHEAR VALUES AVERAGED FOR THE LOW SELECT GRADE BEEF BEFORE APPLYING HDP PROCESS, USING THE SHEAR MAPPING MATRIX

The X-axis represents the column parallel to the connective tissue and the Y axis represents the rows perpendicular to columns. Each combination between the X and the Y represent a specific anatomical location index. The Z-axis is the average shear values obtained.

A definite tenderness gradient (lack of tenderness consistency) existed across the cross section of the control steaks (Fig. 3 and Table 2). For example, a shear value of 6.30 kg was obtained in one location (M12) with a corresponding 3.29 kg value for the M31 location, thus yielding a 3 kg difference in the medial region. Variations of as much as 2 kg were observed in the lateral regions between L12 and L32 (L12 = 3.35 kg and L32 = 5.35 kg). When averaging all the samples the lateral shear force values for C steaks were slightly higher than in the medial region (4.57 vs 4.13 kg). Higher shear values (tougher regions) were identified near the connective tissue separating the medial and the lateral portion of the steaks. Tougher areas were also observed at the edges of the steak, perhaps due to a faster rate of chilling while the muscle was still on the carcass or a temperature increase during the cooking process. Sampling from sites M32, M22, M12, L12, L22, L32 and L42 (the middle row in Table 2) appears to reflect the tenderness (shear force) profile of the control steaks. These values represent the tenderness inconsistencies found in the control steaks. It has been established that a tenderness gradient exists within steaks obtained from the longissimus muscle (Berry 1993). Berry (1993) observed higher shear force measures in the more lateral region of longissimus

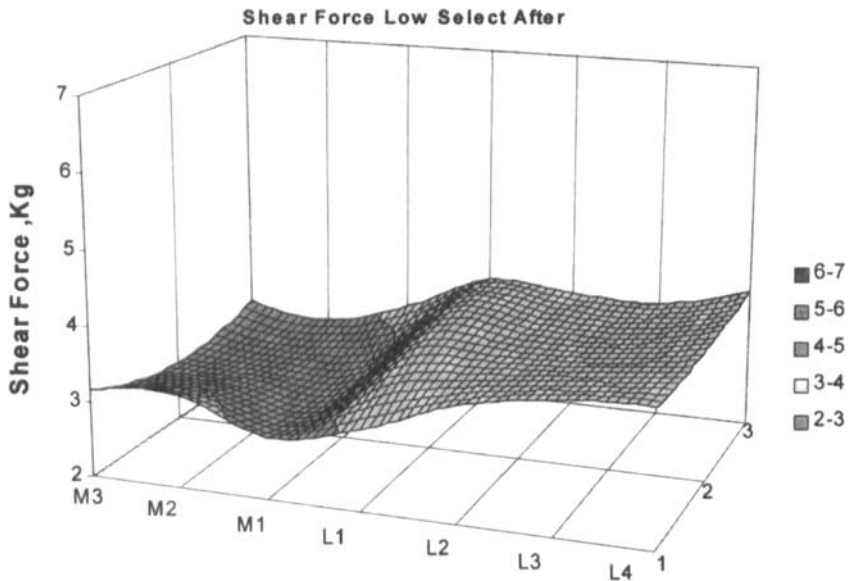


FIG. 4. THREE-DIMENSIONAL REPRESENTATIONS OF SHEAR VALUES AVERAGED FOR LOW SELECT BEEF STRIP LOIN STEAKS AFTER APPLYING HDP PROCESS, USING THE SHEAR MAPPING MATRIX

The X-axis represents the column parallel to the connective tissue and the Y axis represents the rows perpendicular to columns. Each combination between the X and the Y represent a specific anatomical location index. The Z-axis is the average shear values obtained.

observed higher shear force measures in the more lateral region of longissimus muscles, reflecting an increased toughness for that region. Smith *et al.* (1969) reported a large divergence of opinion regarding the degree of a tenderness gradient within the longissimus muscle and the direction of the gradient at any particular location in the muscle. However, they found that cores obtained from the most lateral position on the dorsal side of beef rib steaks consistently produced the highest shear force values. Choosing the sample sites from the middle row of Table 2 for tenderness profiling would at least provide consistent representation of both lateral and medial areas as well as across the cut surface of a steak within a given study.

A successful reduction in the average shear values, as measured with SMM, was obtained using HDP (Fig. 4). Shear-force was improved ($P < 0.01$) by as much as 25% compared to controls (3.27 vs 4.39 kg). Solomon *et al.* (1997) reported as much as a 66% improvement in shear force of beef longissimus muscle compared to the controls when using plastic explosive containers for HDP treatment; however, shear-force values for C samples were as high as 7.8 kg in their study as compared to 4.4 kg for the C samples used in this study.

Using the SMM procedure it was shown that HDP was effective in reducing shear force values and reducing the variability in tenderness within a steak. Shear force variability (SD) was reduced in the medial region from 0.66 to 0.25 for C and HDP, respectively, thus, equalizing tenderness across this area. This suggests that HDP not only reduced shear force (improved tenderness) but also improved the uniformity of tenderness within the steaks. This is also illustrated in Fig. 4 with the contour of the graph flattening out. Shear force variability for the whole steak was reduced from 0.49 to 0.32 for C and HDP samples, respectively.

The greatest improvement in shear force was found in the medial regions of the steaks at the M12 location (near the subcutaneous fat side of the steak). For the HDP samples, no shear values greater than 3 kg at this location were detected and shear force tenderness was improved by 22 to 57% (not presented in a tabular form) compared to the C samples. A value as high as 6.30 kg was observed for the M12 location in the C steaks. By evaluating shear force corresponding to locations within each steak (possible when using SMM), we were able to profile the effect of HDP at reducing tenderness variability across the cross sectional area of each steak. The medial region showed greater tenderness improvements than the lateral region (Table 1). This would imply that, regardless of average shear values, there are inherent properties of muscle in the medial portion that make it different from the lateral portion. More research needs to be performed to identify these properties and the differences between the two regions.

Shear force mapping provided the evidence that variations/inconsistencies in tenderness exist in meat and where these inconsistencies occur. Furthermore, SMM also illustrated the degree of tenderness improvement by location within a steak when using HDP to improve tenderness.

CONCLUSIONS

SMM was developed and evaluated as a tool for profiling the tenderness of a cut of meat and the improvement to the meat resulting from a postharvest tenderization process (HDP). The tenderness inconsistencies of control-untreated steaks related to an anatomical location across the steak surface area could be identified and the response of these locations to a tenderization process could be followed and thus test the efficacy of the tenderization process, in this case HDP technology. SMM can be used to assess for anatomical differences within cuts of meat and for tenderness variations between the cuts. When considering reference point methodology, SMM may be employed to compare results between studies and laboratories, providing a more precise tool for testing for tenderness conditions and responses to postharvest intervention technologies.

REFERENCES

- ALSMeyer, R.L., THORNTON, J.W. and HINER, R.L. 1965. Some dorsal lateral location tenderness differences in the longissimus dorsi muscle of beef and pork. *J. Anim. Sci.* 24, 526-530.
- AMSA. 1995. *Research Guidelines for Cookery, Sensory Evaluation and Instrumental Tenderness Measurements of Fresh Meat*. American Meat Science Assoc., Chicago.
- BERRY, B.W. 1993. Tenderness of beef loin steaks as influenced by marbling level, removal of subcutaneous fat, and cooking method. *J. Anim. Sci.* 71, 2412-2419.
- BOCCARD, R., BUTCHER, L., CASTEELS, E., CONSENTINO, E., DRANSFIELD, E., HOOD, D.E., JOSEPH, R.L., MACDOUGALL, D.B., RHODES, D.N., SCHON, I., TINBERGEN, B.J. and TOURAILLE, C. 1981. Procedures for measuring meat quality characteristics in beef production experiments. Report of a working group in the commission of the European Communities beef production research programme. *Livestock Prod. Sci.* 8, 385-397.
- CHRYSTALL, B.B. and DEVINE, C.E. 1991. Quality assurance for tenderness. *Mirinz Rev.* 126. New Zealand.
- DRANSFIELD, E. and MACFIE, H.J.H. 1980. Precision in the measurement of meat texture. *J. Sci. Food Agric.* 31, 62-66.
- EASTRIDGE, J.S. and SOLOMON, M.B. 1996. Variability in the shear force test for meat: Sample considerations. *J. Anim. Sci.* 75(Suppl. 1) abstr., 94.
- EASTRIDGE, J.S., SOLOMON, M.B., WEST, R.L. and CHASE, C.C. 2000. Tenderizing meat from Brahman cattle: Hydrodynamic pressure process and within-muscle effects for bottom round. *J. Anim. Sci.* 78(Suppl. 1) abstr., 161.
- HONIKEL, K.O. 1998. Reference methods for the assessment of physical characteristics of meat. *Meat Sci.* 49, 447-457.
- KASTNER, C.L. and HENRICKSON, R.L. 1969. Providing uniform meat cores for mechanical shear force measurement. *J. Food Sci.* 34, 603-605.
- MORGAN, J.B., MILLER, K., MENDEZ, F.M., HALE, D.S. and SAVELL, J.W. 1991a. Using calcium chloride injection to improve tenderness of beef from mature cows. *J. Anim. Sci.* 69, 4476-4496.
- MORGAN, J.B., SAVELL, J.W., HALE, D.S., MILLER, R.K., GRIFFIN, D.B., CROSS, H.R. and SHACKELFORD, S.D. 1991b. National beef tenderness survey. *J. Anim. Sci.* 69, 3274-3283.
- SAS. 1996. SAS System for Windows, Release 6.12. SAS Inst., Inc. Cary, N.C.
- SHACKELFORD, S.D., WHEELER, T.L. and KOOMARAIE, M. 1997. Tenderness classification of beef: I. Evaluation of beef longissimus shear force at 1 or 2 days postmortem as predictor of aged beef tenderness. *J. Anim. Sci.* 75, 2417-2422.

- SMITH, G.C., CARPENTER, Z.L. and KING, G.T. 1969. Considerations for beef tenderness evaluations. *J. Food Sci.* 34, 612-618.
- SOLOMON, M.B., LONG, J.B. and EASTRIDGE, J.S. 1997. The Hydrodyne-a new process to improve beef tenderness. *J. Anim Sci.* 75, 1534-1537.
- SOLOMON, M.B. 1998. The Hydrodyne process for tenderizing meat. 51st Proc. Annual Reciprocal Meat Conference. pp. 172-176, Am. Meat Sci. Assoc. Kansas City, Mo.
- ZUCKERMAN, H. and EASTRIDGE, J.S. 2001. Personal communication.